ON THE DETERMINATION OF THE FIELD DIFFRACTED BY A HOLOGRAPHIC GRATING

D. Maystre and R. Petit

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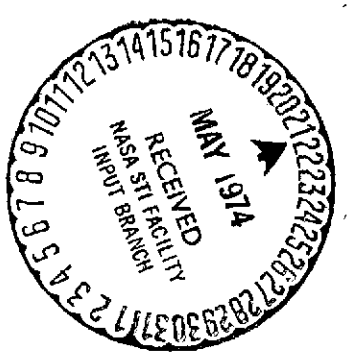

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16. Abstract

The article deals with the theoretical determination of light efficiencies for "holographic gratings." Some numerical results are given to emphasize the influence of grating shape constants.

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ON THE DETERMINATION OF THE FIELD DIFFRACTED BY A HOLOGRAPHIC GRATING

D. Maystre and R. Petit
Laboratoire d'Optique Electromagnetique, Faculte des Sciences de Marseille, Centre de Saint-Jerome, France
(Electromagnetic Optics Laboratory, Faculty of Sciences of Marseille, Center of Saint Jerome, France)

1. INTRODUCTION

The Jobin-Yvon structure of holographic gratings has been described in [1]. It /309* consists of a flat base coated with a photopolymerizable resin which records the interference phenomena produced by two coherent point sources; after development, rinsing, drying and coating with metal, one obtains a diffraction grating, whose profile is poorly known. This paper contains the first results of a numerical study of this type of grating treated as infinite conductors.

2. THE PROFILE OF THE HOLOGRAPHIC GRATINGS

Several Jobin-Yvon gratings have been examined at the Laboratoire de Physique Cristalline de la Faculte des Sciences de Marseille (Crystal Physics Laboratory of the Faculty of Sciences of Marseille) and Fig. 1 reproduces one of the many photographic negatives already obtained by electron microscopy [2]. It is from such photographs that we have made the profile determinations necessary to calculate the efficiency[1] : those which we are going to report have been done by comparing the generatrix of the grating to a curve derived from an "abbreviated cycloid" by an affine transformation orthogonal to the Ox axis; its parametric equations are:

$$x = u - A \sin Ku,$$
$$y = B (1 + \cos Ku),$$

where u is the parameter, B and A are two constants fixing, respectively, the depth H of the rulings (H = 2B) and their width at half-depth (Fig. 2), K is the spatial

*Numbers in the margin indicate pagination in the foreign text.

[1] The efficiency in a given order is the ratio of the flux diffracted in this order to the incident flux.

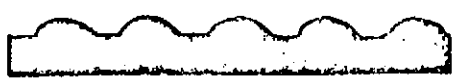

Fig. 1. Electron micrograph of the profile of a holographic grating. (Laboratoire de Physique Cristalline de la Faculte des Sciences de Marseille) [Crystal Physics Laboratory of the Faculty of Sciences of Marseille].

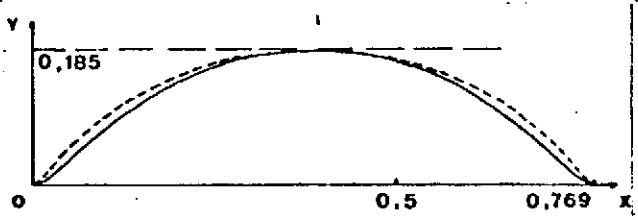

Fig. 2. Possible profiles of two holographic gratings of the same height, H = 0.24d. ——— A = 0.09 d, ------ A = 0.12d. The unit of length is μ m.

frequency of the grating (K = 2π/d) and for all the calculations presented the spacing d is equal to 1/1300 mm.

3. THE CALCULATION METHODS EMPLOYED

We have used the formalism recently described by Pavageau [3]. The two integral equations pertaining to the two fundamental polarization cases designated, respectively, E// or H// depending on whether the electric field E or the magnetic field H is parallel to the rulings, are very similar. These are the Fredholm equations of the second kind, of the form:

$$\phi(x) = \phi_0(x) + \int_0^d N(x,x')\,\phi(x')\,dx' \,, \qquad /310$$

where $\phi_0(x)$ is a known periodic function, N(x, x') is a bounded kernel given by a continuous series, periodic in x and x', $\phi(x)$ is the unknown periodic function, related to the surface density of the current, from which one can obtain the diffracted field in entire space.

For our first calculations we have used the iteration method suggested by Pavageau [3]. When it was found to be inefficient, it was replaced by the simpler method already successfully used by Bolomey for diffracting objects with finite dimensions [4]. The interval (O, d) is divided into P intervals C_j (j = 1, ..., P) over each of which one assumes that the functions $\phi(x)$ and $\phi_0(x)$ maintain a constant value ϕ_j and ϕ_{0j} . The Fredholm equation then leads to a linear system:

$$\phi_i = \phi_{0i} + \sum_{j=1}^{P} \phi_j \int_{C_j} N(x_i,x')dx' \,,$$

which allows the ϕ_j to be determined when one has calculated the integrals which enter into its coefficients. This calculation of the simple integrals presents no problems and reduces to tabulating the values of the kernel.

4. RESULTS

In order to attempt to analyze the effect of the depth H and of the width at half-depth, we have plotted an efficiency curve as these parameters vary. The curve gives the efficiency as a function of the incidence angle θ in the -1 order and for a constant deviation of 13 degrees.

4.1 Effect of ρ = H/d

Figures 3 and 4 give the efficiency curves corresponding to 4 different values of ρ for a fixed width at half-depth (A = 0.09d).

The iteration method was used for the three smallest values of ρ, under the condition that the result be not too close to θ values at which there is a Wood's anomaly; the conservation of energy has therefore always been verified to better than about 5%. For ρ = 0.3, because of a very frequent lack of convergence of the iteration process, we have preferred using a discrete method: the P values of the order of 50 to 70 have always permitted verification of energy conservation to better than about 2% in the E// case, but we sometimes had to be content with 6% in the H// case.

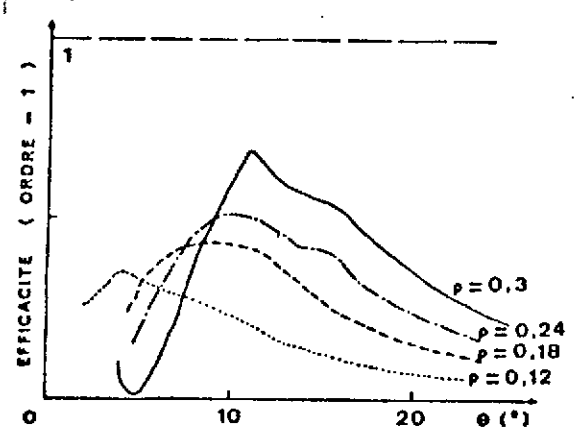

Fig. 3. E// case; the effect of ρ on the efficiency curve.

a) E// case (Fig. 3).

In this type of profile, we first note the regularity of the curves and, rather intuitively, the presence of a "blaze effect."[2] The values of maximum efficiency and of

[2] A "blaze effect" is said to be present in a given order when almost all the diffracted energy is found in this order.

the blaze angle[3] increase with ρ: if $\rho = 0.3$, the maximum is a value near 0.7 for $\theta =$ 10.5 degrees (which corresponds to a wavelength of about 0.45 μm).

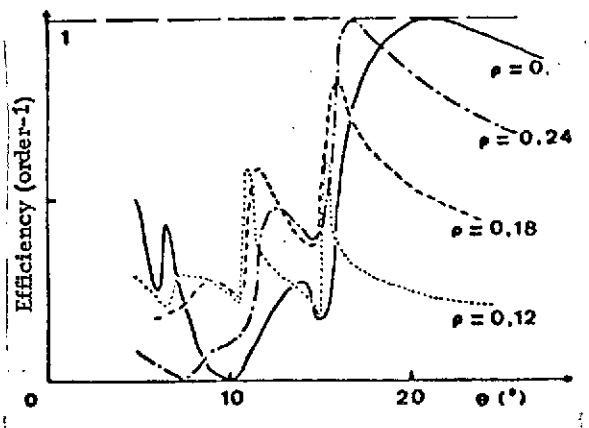

Fig. 4. H// case; the effect of ρ on the efficiency curve.

b) H// case (Fig. 4).

The curves are much less regular; /311 two parts can be distinguished — the left part, corresponding to incidence angles less than about 15 degrees, is very irregular; the presence of "gaps" associated with the proximity of Wood's anomalies can be seen, making certain practical uses of the gratings difficult.

The right part is much more regular and a very pronounced "blaze effect" is evident; the maximum efficiency is practically equal to 1 for the two largest ρ values.

The "blaze angle" and the width of the peak increase with ρ. For $\rho = 0.3$, one observes a maximum approaching 1 for an incidence angle equal to 21 degrees (which corresponds to a wavelength of about 0.7 μm).

Increasing ρ thus seems to be worthwhile: on the one hand, the blaze effect increases, while on the other hand the "gaps" are removed from the blaze angle.

4.2 Effect of the width at half-depth

Figure 2 compares the profile of the grating studied in the previous paragraph (solid line) ($\rho = 0.24$, A = 0.09d) with that of a grating with the same height but a different width at the half-depth (dashed line) (A = 0.12d). Figures 5 and 6, referring

[3] The incidence angle corresponding to maximum blaze effect is called the "blaze angle."

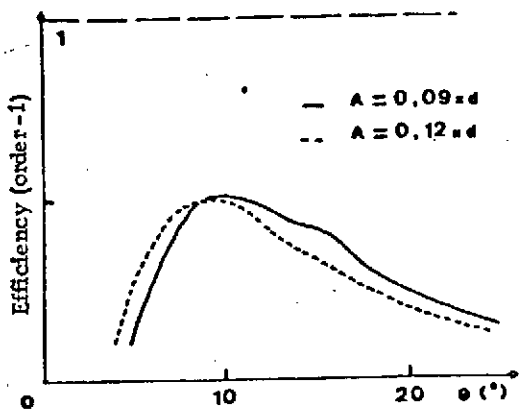

Fig. 5. E// case; the effect of the width at half-depth on the efficiency curve.

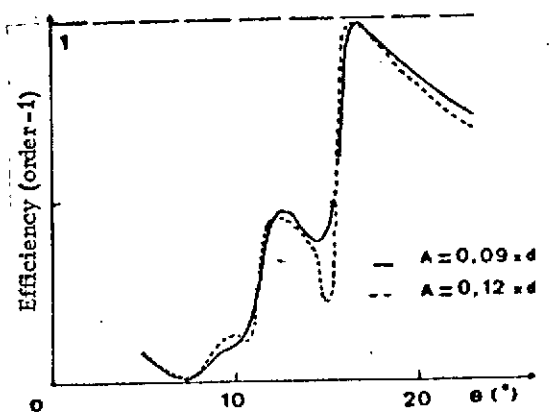

Fig. 6. H// case; the effect of the width at half-depth on the efficiency curve.

to the two polarization cases, clearly show that the width at half-depth here is a parameter without much effect on the efficiency curve.

In this theoretical and numerical study we have confirmed the properties of the holographic gratings described by the Jobin-Yvon researchers:

- the existence of a "blaze effect" which is as important as for echelette gratings;

- efficiency curve irregularities in the vicinity of the Wood's anomalies.

The quantitative comparison, for a given grating, of our results with experimental results has not been done since the electron microscopy methods employed up to now do not give us the grating profile with the necessary precision. Studies are in progress to remedy this situation.

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